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Project No: A-2162

Project Director: J. A. Knight

Sponsor: Hague International

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CA–4 (1/79)

A-2162

ANALYSIS AND CHARACTERIZATION OF CARPET WASTES SAMPLES

by

J. A. Knight
L. W. Elston
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Report No. 2

for

HAGUE INTERNATIONAL
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September 30, 1978

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1. ABSTRACT

A mixture of carpet waste materials (selvage, 50.4 percent; splices and scraps, 14.2 percent; lint, 6.4 percent; and paper and cardboard, 29.0 percent by weight) was prepared and a series of preliminary burning experiments were conducted. These burning experiments were conducted on a batch basis with small quantities and were of short duration. Eight trial burns were made with one gram samples in a closed apparatus designed to measure the input air and to collect all of the combustion products for analysis. Due to detonations that occurred in the initial phase of each trial burn, the decision was made to focus on open-grate burns.

Six open-grate burns were made; three with a closed cover provided with a gas sampling probe and three with a concial hood and stacks (one 12 inches long and one, 72 inches). Samples of the combustion gases were taken with a sampling probe in each stack. The combustion of carpet waste appeared to proceed in a stepwise fashion with the small batch samples. The paper and jute fiber in the sample ignite readily, and the combustible gases from the burning fraction are simultaneously consumed. After a few (up to 30) seconds, the synthetic fibers and the latex slowly fuse to form bubbling globules of molten polymer. If heat and air are continually supplied, these globules are carbonized and burned, leaving an ash residue. If the supplied heat source is removed, the combustion of the polymer globules does not proceed to completion. Gases evolved from the decomposing polymer are highly combustible and burned rapidly. After the combustion of the polymer has proceeded to the carbonized state, the carbonized (charcoal like) mass continues to burn cleanly without additional supplied heat.

The gas samples were analyzed for nitrogen, oxygen, carbon monoxide, carbon dioxide, hydrogen, methane, ethylene, propylene, butane, nitrogen dioxide, and hydrogen cyanide. Moderate concentrations of hydrogen cyanide were detected in the reducing (oxygen starved) region of the flame, but not in the air-rich gas sampled above the flame. Small quantities of nitrogen oxides were detected in the stack gases. Carbon monoxide levels varied from a maximum of two percent in the reducing flame region to zero in the stack gas. Hydrocarbon concentrations (the sum of methane, ethane, ethylene, propane, propylene and butanes) in the stack gases varied from 0.7 percent above a burn with limited air to a few parts per million above a fire with 75 percent excess air.

These results with the priliminary burns indicate that the carpet wastes can be burned satisfactorily to an ash which contains no combustible material and that the combustion gases are essentially nonpolluting. The next experimental burns of the carpet waste will be continuous burns with secondary combustion. A metered supply of air will be fed to the combustion chamber, and gas samples will be obtained from the stack. These burns should provide adequate data to make reliable predictions of the burning behavior of mixed carpet wastes on a continuous basis.

2. INTRODUCTION

The experimental work described below consisted of preliminary efforts to simulate the combustion of mixed carpet waste under practical incinerator conditions, to observe the burning properties of the mixtures, and to observe the effect of firing conditions on the composition of the gases evolved.

The major objective of the preliminary firings was to obtain gaseous samples of the gases from the burning carpet wastes for analysis by gas chromatography for determination of the major components. The presence of nitrogen oxides and hydrogen cyanide was also of interest. The approaches used in the preliminary experiments involved trial burns of ground carpet waste in a closed system and burns of small pieces of carpet waste in an open system.

3. EXPERIMENTAL

3.1 Sample Preparation

The finely ground mixed samples for the closed system burning experiments were prepared by coarsely grinding selected pieces of carpet wastes A, B, C and D, pieces of broken cone, and paper in a Model 4 Wiley Mill, mixing the coarsely ground materials and passing the mixture through the Wiley Mill using a fine (2 mm) screen. The finely ground sample was thoroughly remixed and stored in an air tight container.

The coarse, unground sample mixture for the open grate experiments was prepared by cutting rectangular scraps of selvage (50.4 percent by weight) splices and scraps (14.2 percent by weight), and laboratory paper towels and cardboard boxes (29.0 percent by weight). Carpet lint (6.4 percent by weight) was taken partly from the free lint available in the supplied sample lot and partly from pile pulled from assorted carpet scraps. These components were thoroughly remixed before each burn experiment. Samples for each burn experiment were collected by random crabs from the remixed bulk sample.

3.2 Analytical Methods

The concentrations of the major components in the combustion off-gases were determined by gas chromatography, utilizing a gas chromatographic analytical

facility with four gas chromatographs.

The concentration of hydrogen cyanide in the gas samples taken from the reducing region of the flame and from the stack gases above the flame were determined by passing a known volume of the off gas through a dilute (0.25 N) aqueous sodium hydroxide solution and measuring the dissolved cyanide by the APHA Pyridine-Pyrazolone Method (1).

The concentrations of nitrogen oxides in the flame and in the stack gases were determined by APHA Tentative Method 403 (2).

On line monitoring was accomplished by a Thermox WDG-P (3) and a Lira Model 303 Infrared Analyzer (4) operated in parallel. The Thermox instrument was operated in its "excess fuel" mode. Calibration scales supplied by the manufacturers rather than laboratory calibrations were used to interpret the readings from these instruments.

3.3 Burning Experiments

3.3.1. Closed System: Burning experiments of mixed finely ground carpet waste and cone were tried in a closed 500 ml stainless steel vessel heated by a crucible furnace. The closed system (Figure 1) consisted of a 500 ml stainless steel kettle with a top flange and gasket mated to a resin kettle cover. Air was forced at a controlled rate into the bottom of the container below a bed of alumina spheres, which served as a grate, and the air flow rate was measured by a dry test meter connected through a gas outlet line to the upstream side of the air inlet. A tee in the air line permitted diversion of the air flow to be set in advance of a burn experiment. The internal temperature was measured by a thermocouple passed through another opening in the cover. Heat was supplied by a 5 inch Hoskins crucible furnace, which closely fitted the sides of the metal container. Weighted (approximately 1 g) samples were lowered into the apparatus by means of a nichrome wire passed through a cork in the top of a 20 mm Pyrex tube fitted to a third opening in the cover.

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1. APHA STANDARD METHOD, 13th cu. 404 American Public Health Association, Washington, D.C., 1971.
2. Methods of Air Sampling and Analysis, American Public Health Association, Washington, D.C., 1972, p. 329.
3. Thermox Instruments, Inc., 6592 Hamilton Ave., Pittsburgh, PA 15206.
4. Mine Safety Appliances Co., 201 N. Braddock Ave., Pittsburgh, PA 15208.

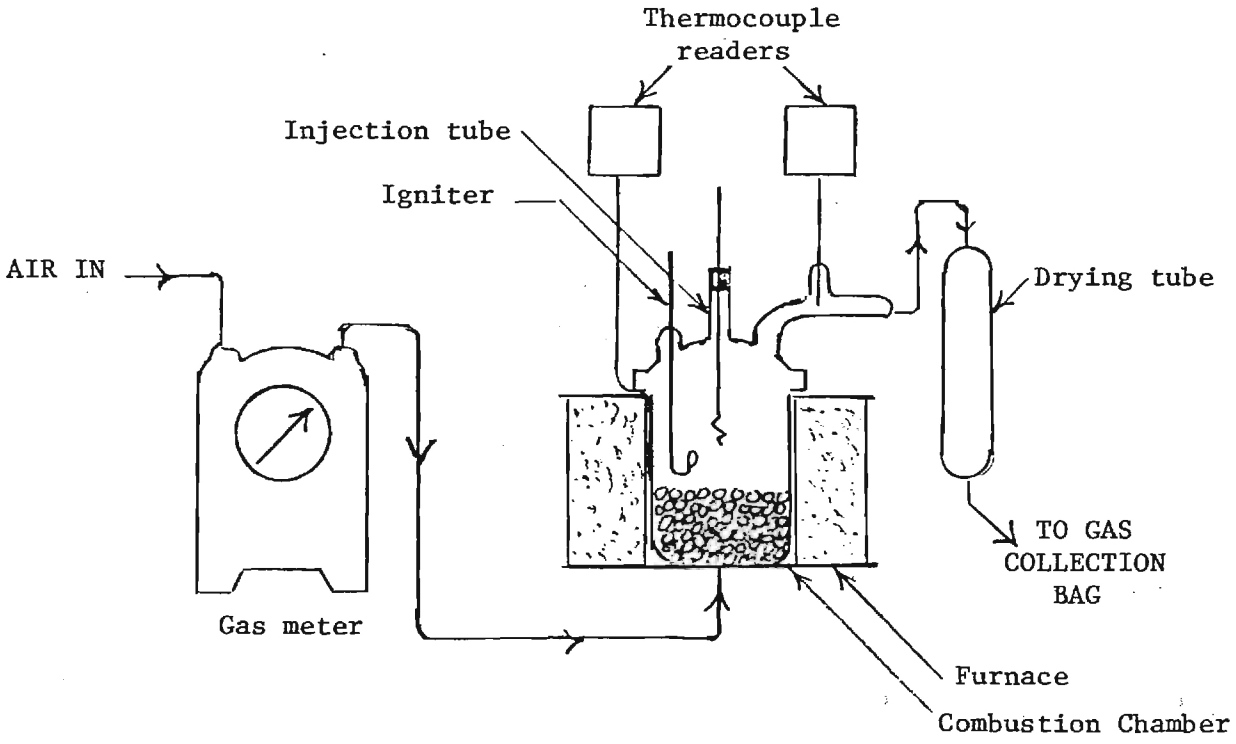

Figure 1. CLOSED COMBUSTION APPARATUS

The combustion chamber was preheated to the desired temperature (700°C) and a constant air flow rate was established through the apparatus and the gas meter. The sample was loaded into the top of the Pyrex tube, which was then set into the cover. The sample was quickly lowered to the grate by forcing the nichrome suspension wire downward through the cork, and the gas stream was diverted from the exhaust to the gas collection bag. The rapidly evolved gases would detonate preventing a steady smooth combustion of the sample. Ignition devices such as fuse paper and a continuous gas flame did not prevent detonation of gases evolved from the sample during the time between insertion and ignition. The decision was made to discontinue these experiments and to conduct a series of open grate firings.

3.3.2: Open Grate Burning Without Stack: The first open grate burning experiments were conducted in a 12 inch diameter brazier (portable barbecue grill) (Figure 2). The feed material was placed on the grating and ignited by means of a Bunser burner flame, which was maintained during the entire burn. Gases were sampled through a copper line passed through one end of a 12 inch x 8 inches x 6 inches deep rectangular stainless steel pan inverted approximately 14 inches above the grate. Gas samples were taken 30 seconds and 90 seconds after ignition, corresponding to periods of cellulose (mainly paper and jute) only burning and whole sample burning, respectively. The feed for this experiment was 250 g of the mixed feed described in 3.1.

The second firing in this apparatus was conducted with 50 g of mixed material supported on a metal plate placed on top of the grate. The gases were sampled after about 50 percent of the fuel has been consumed. An attempt to make a continuous gas analysis with "on-line" analyzers was not successful because the heated plastic line collapsed leading to the instruments.

The third burning experiment was conducted with 150 g of mixed material on the grate. Substitution of a 36 inch metal tube for the plastic line of the on-line analyzer sampling train permitted a continuous trace of the carbon dioxide and excess combustible gases (loosely defined as a mixture of CO, CH_4 and/or H_2) evolved during the run.

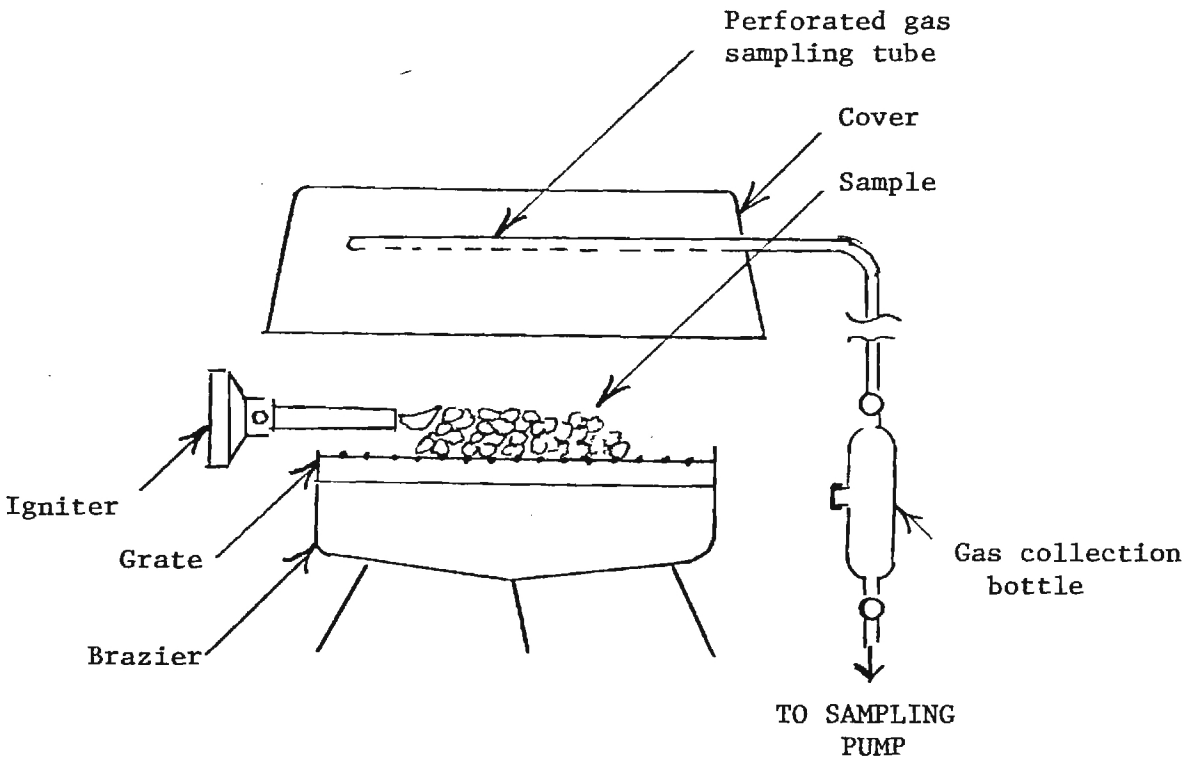

Figure 2. OPEN GRATE WITH CLOSED COVER

3.3.3. Open Grate Burning with Short Stack: In order to provide a suitable draft above the fire, a 12 inch OD conical hood was fabricated with a 3 inch ID stack 12 inches long. A damper was placed in the stack to regulate the rate of convection. A schematic diagram of the apparatus is shown in Figure 3.

This apparatus configuration was used in burn experiments with a short stack ("D" = 12 inches) and then with a long stack ("D" = 72 inches).

A 150 g sample of mixed waste was burned on the grate, under the conditions used for the first and third burns except that the flow of air above the burning sample was increased by convection through the 12 inch stack. During the entire burn a gas sample was drawn through an impinger containing 0.25N aqueous sodium hydroxide. This integrated cyanide sample was later analyzed by a colorimetric method equivalent to APHA Method 404 (5):

3.3.4. Open Grate Burning with Long Stack: To increase the convection rate, thus, the concentration of excess air above the burning sample, a conical hood with a 72-inch stack was employed. This experimental arrangement differed from that shown in Figure 3 only in the length of the vertical stack.

A 220 g sample of mixed waste burned smoothly, producing little visible smoke above the flame and none from the stack. Gas bottle (grab) samples were taken 90 seconds and 150 seconds after the start of the burn. A continuous slow stream of gas (1.3 liters total) was drawn through an impinger containing 192 ml of 0.25N NaOH solution during the entire run to collect an integrated sample for colorimetric cyanide analysis.

The second burn in the long stack apparatus was a duplicate of the experimental firing described above. Samples for gas analysis were taken 90 seconds, 150 seconds, and 210 seconds after the start of the burn. These samples were used for determination of the major combustion gas components and for the colorimetric determination of nitrogen oxides (NO_x).

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5. Hach Chemical Company Cyan-Ver colorimetric method, Ames, Iowa.

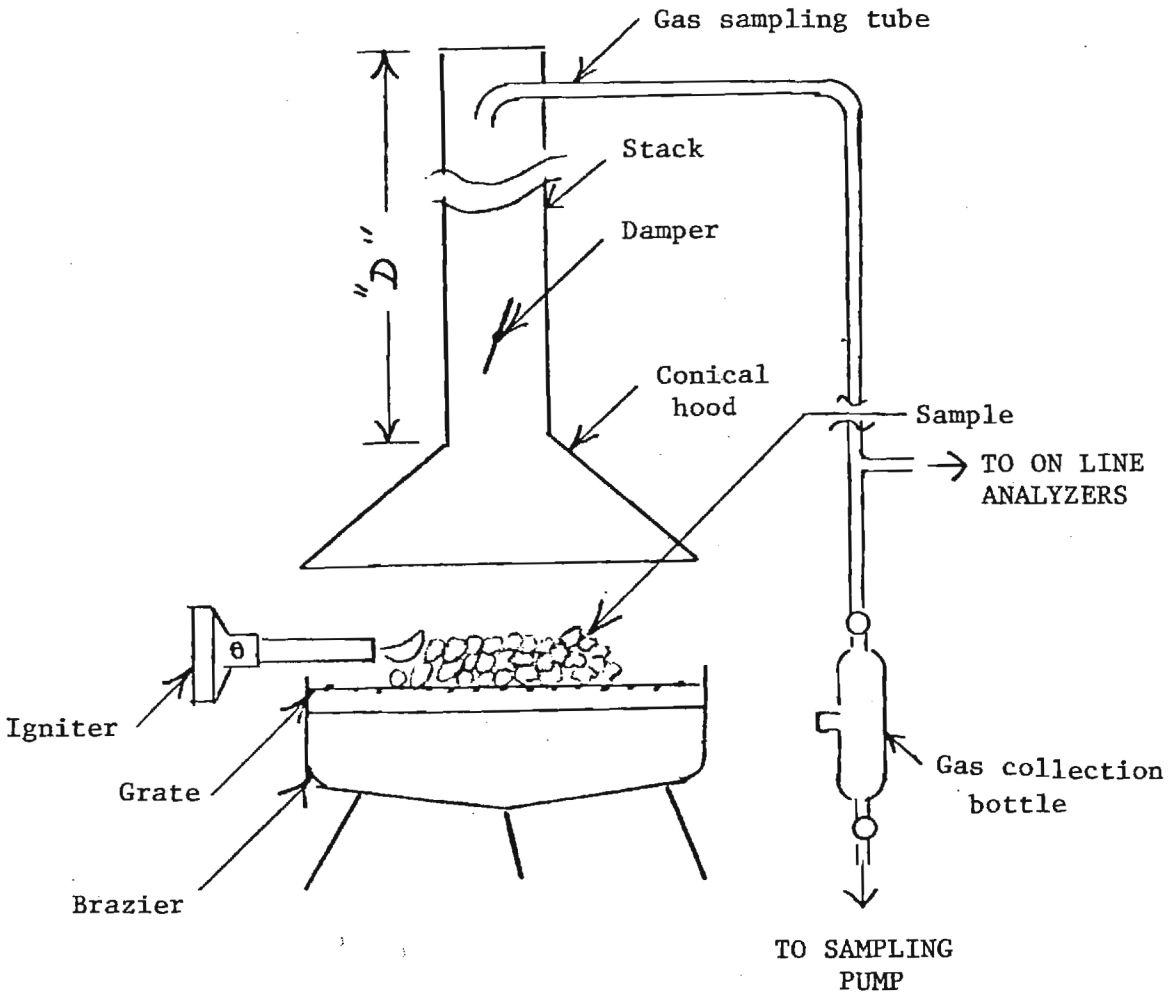

Figure 3. OPEN GRATE WITH STACK

4. RESULTS AND DISCUSSION

4.1 Closed System Burning Experiments

Burning waste samples in a closed system in an attractive experimental method, because all of the inputs can be measured, and all of the outputs can be collected for analysis. Using a fairly thick bed of alumina spheres at red heat to simulate a grate provides a heat reservoir to prevent a large temperature drop when a sample is injected.

When finely ground carpet waste charges were injected into the apparatus, Figure 1, the gases from the heated polymer detonated after 5 to 10 seconds. The violence of an early detonation was conspicuously less than one which was delayed. Ignition of the solid sample occurred a few seconds after the initial gas detonation and the combustion to ash proceeded smoothly. The detonations persisted even after addition of fuse papers to the charge and insertion of a gas fired pilot flame into the chamber. Each detonation blew one or more of the stopper or inserted probes out of the covers, and therefore, the off-gas samples were lost.

It is not certain whether the delayed detonations were due to an inadequate ignition device or to the rise of the flammable gas concentration to a sharply defined explosive level. As this problem would not occur in a continuously fired incinerator, the decision was made to concentrate on some preliminary open grate burning tests.

4.2 Open Grate Burning Without Stack

4.2.1. Burn I: In the initial open grate firing the cellulosic fraction of the sample was well ignited 30 seconds after the small continuous gas flame was lit, and the polymeric material began to melt, carbonize, and ignite after 90 seconds. Analytical results from the gas samples taken 30 seconds after initiation (cellulosic combustion stage) and 90 seconds after initiation (polymer combustion stage) are given in Table 1.

Table 1. OFF-GAS ANALYSIS OF BURN I

Elapsed time	30 seconds	90 seconds
Gas	% Volume	% Volume
Oxygen	6.0	5.8
Nitrogen	82.1	81.1
Carbon Monoxide	0.7	1.9
Carbon Dioxide	9.9	9.6
Hydrogen	0.81	0.81
Methane	0.07	0.40
Ethylene	0	0
Propylene	0	0
Butanes	0	0.02
Nitrogen Dioxide	0 ppm.	0.08 ppm.

The cellulosic portion of the sample was burning smoothly with little visible smoke after 30 seconds. After 90 seconds about half of the material had been consumed, and there was no obvious increase in the smoke emitted. The entire burn was completed in 4.6 minutes, having a voluminous, slightly darkened ash. The presence of roughly six percent oxygen in the gases above the burn indicates roughly 30 percent excess air at the sampling point sixteen inches above the fire. It was believed that the burn occurred in a relatively oxygen poor condition, but less than 0.5 percent unburned hydrocarbon was found in the off-gas.

4.2.2. Burn II: The purpose of the second burn in this apparatus was to add a recording on-line Lira infrared analyzer for carbon dioxide and a Thermox instrument for combustible gases. The sample burned freely with very little visible smoke. Shortly after ignition of the 50 g ground waste sample the plastic line connecting the cover and the instruments softened and collapsed. The experiment indicated that the infrared analyzer could follow the composition of carbon dioxide during a burning experiment if provided with an adequate sampling line. No useful analytical data were obtained from this experiment.

4.2.3. Burn III: For the third burn in this apparatus a six-foot length of metal tubing was inserted between the cover and the plastic intake line of the "on-line" analyzers. The 150 g charge of unground mixed waste burned smoothly

with little visible smoke. The recorder trace from the on-line monitor is shown in Figure 4.

A gas sample for chromatographic analysis was taken 150 seconds after ignition, when approximately 50 percent of the full volume of the sample was consumed. The results of this analysis are shown in Table 4.

Table 2. OFF-GAS ANALYSIS OF BURN III

Elapsed time	150 seconds
Gas	% Volume
Oxygen	14.6
Nitrogen	81.8
Carbon Monoxide	0
Carbon Dioxide	3.15
Hydrogen	0
Hydrocarbons (all)	0
Nitrogen Dioxide	0.003 ppm.

The carbon dioxide trace from the infrared analyzer and the excess combustible gas (loosely defined as the sum of the concentrations of carbon monoxide, hydrogen, and hydrocarbons) are shown in Figure 4. In the recorder trace the percent carbon dioxide in the off gas stream rose sharply a few seconds after agnition. The overall rise continued irregularly to a maximum near 150 seconds, and then the carbon dioxide concentration decreased until 100 percent of the fuel was consumed. The plateau following the 100 percent fuel consumption point represented carbon dioxide from the ignition burner. The combustible gas trace remained well below one percent. Since the Thermox output is logarithmic, it would be difficult to make a quantitative estimate from the recorder trace.

Comparing the results of gas chromatographic analysis with the readouts from the "on-line" instruments shows the "on-line" readouts to be high. The gas chromatographic results are considered to be nearly correct, as these instruments have repreatedly shown good agreement with the known concentrations in calibration gas mixtures. Although the new "on-line" analyzers obviously require additional

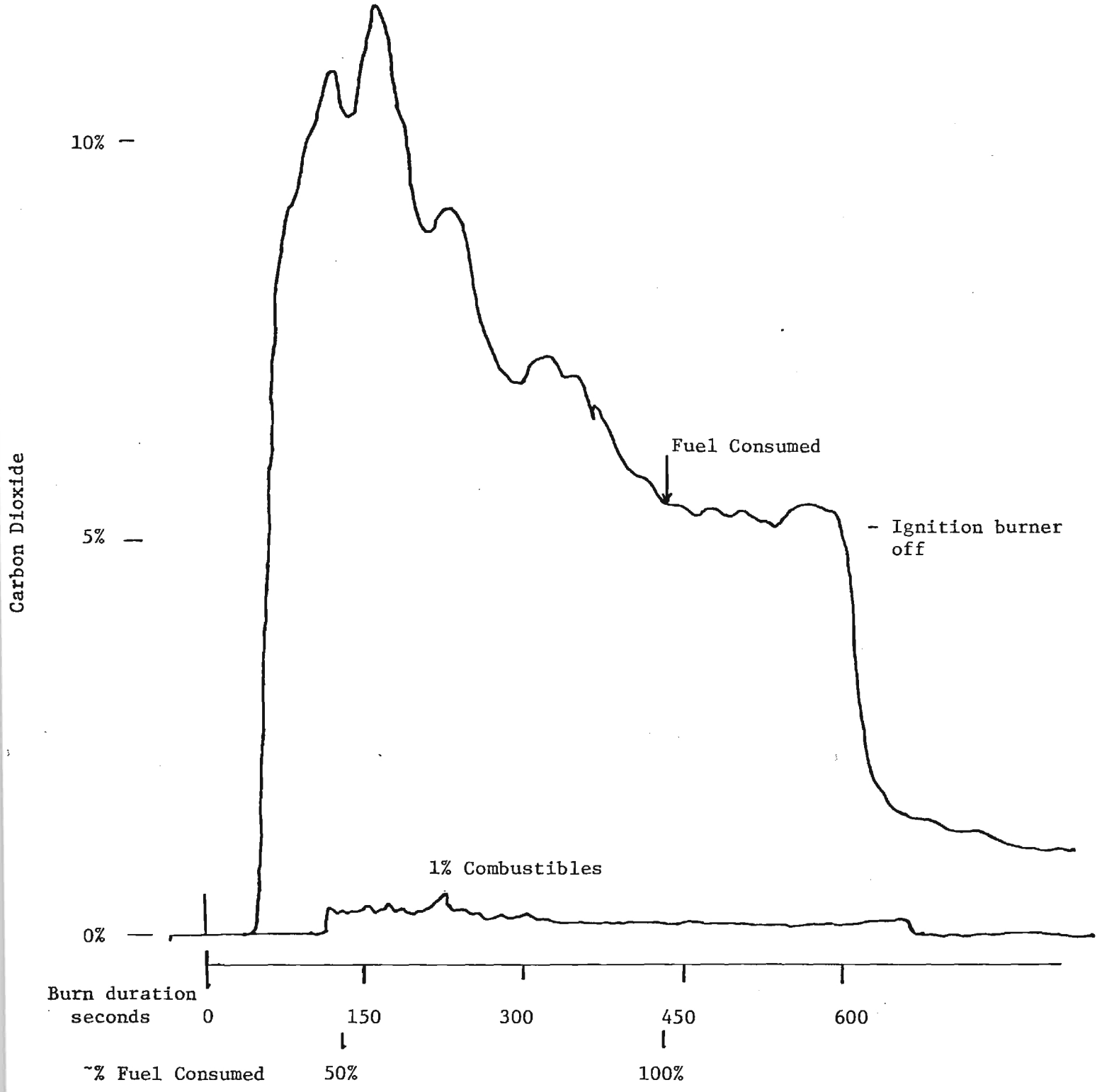

Figure 4. ON LINE CO_2 AND COMBUSTIBLES RECORDING OF BURN III

calibration, their output can furnish qualitative information about the progress of the burn.

4.3 Open Grate Burning with Conical Hood and Stack

4.3.1. Burn IV: As the closed cover limited the flow of air into the combustion zone and the escape of combustion gases, a conical hood with a stack and damper was fabricated for use with Burn IV. (See Figure 3). In this burn with the conical hood and a 12 inch stack, a 210 g charge of carpet waste was ignited and burned with the stack damper fully open. The "on-line" analyzers were not used for this experiment. Off gas samples were taken 90 seconds and 150 seconds after ignition. A continuous stream of gas was drawn through a second gas sampling tube into air impinger containing 0.25N sodium hydroxide for an integrated cyanide analysis over the entire run. The sample burned vigorously with the flame reaching the top of the stack during the peak of the cellulosic combustion phase. Results of the gas analyses are shown in Table 3.

Table 3. OFF-GAS ANALYSIS OF BURN IV

Elapsed Time	90 seconds	150 seconds
Component	% Volume	% Volume
Oxygen	5.8	14.2
Nitrogen	69.8	81.0
Carbon Monoxide	2.0	0
Carbon Dioxide	11.3	4.8
Hydrogen	0.44	0
Methane	0.6	370 ppm.
Ethylene	0.1	9 ppm.
Propylene	80 ppm.	0 ppm.
Butane	1100 ppm.	0 ppm.
Nitrogen Dioxide	0.1 ppm.	0.1 ppm.
Hydrogen Cyanide*		142 ppm.

*Integrated sample over entire burn

The escape of flame from the top of the stack, the low percent oxygen in the 90 second sample, and the presence of hydrogen cyanide in the integrated sample were taken to indicate incomplete combustion of the off-gases during the vigorous part of the burn, and therefore, the need for a longer stack. The weight of the ash from this burn was 24 percent of the original charge weight. No unburned material was observed in the ash.

4.3.2. Burn V: The two burns made with the long stack (D = 72 inches in Figure 3) progressed smoothly. The flame was clear, and no smoke was observed. Gases were sampled 11 inches below the top of the stack. The feed sample was 210 g of unground mixed waste.

The analytical results from gas samples taken at 90 seconds and 150 seconds into the Burn V with the long stack are shown in Table 4.

Table 4. OFF-GAS ANALYSIS OF BURN V

Elapsed Time	90 seconds	150 seconds
Component	% Volume	% Volume
Oxygen	11.6	17.3
Nitrogen	79.9	80.0
Carbon Monoxide	0	0
Carbon Dioxide	8.5	2.7
Hydrogen	0	0
Methane	7 ppm.	240 ppm.
Ethylene	14 ppm.	4 ppm.
Propylene	0 ppm.	0 ppm.
Butanes	0 ppm.	0 ppm.
Nitrogen Dioxide	0.06	0.07 ppm.
Hydrogen Cyanide*		2.3 ppm.

*Integrated sample over entire burn.

The ash weight from this burn was 30 percent of the sample weight. No unburned combustible material remained. The low concentrations of combustible

gas (carbon monoxide, hydrogen, and hydrocarbons) and hydrogen cyanide are attributed to an increased overfire draft as indicated by the high percent oxygen.

4.3.3. Burn VI: A duplicate experiment was conducted under conditions as near as possible to those in Burn V above except that a third gas sample was taken 210 seconds after ignition. Results of the gas analysis are given in Table 5.

Table 5. OFF-GAS ANALYSIS RESULTS OF BURN VI

Elapsed time	90 seconds	150 seconds	210 seconds
Component	% Volume	% Volume	% Volume
Oxygen	12.6	9.35	16.9
Nitrogen	80.2	81.2	80.2
Carbon Monoxide	0	0	0
Carbon Dioxide	7.2	9.5	2.9
Hydrogen	0	0	0
Methane	2 ppm.	15 ppm.	14 ppm.
Ethylene	0.4 ppm.	5.7 ppm.	14 ppm.
Propylene	0 ppm.	0 ppm.	0 ppm.
Butanes	0 ppm.	0 ppm.	0 ppm.
Nitrogen Dioxide	0.016 ppm.	0.017 ppm.	0.017 ppm.
Hydrogen Cyanide*			3 ppm.

*Integrated sample over entire run.

As in Burn V the 30 percent residual ash contained no unburned combustible material. While not identical to those in Burn V, the off gas samples show low combustible gas residue and reasonably low nitrogen oxide emissions. There were no experimental observations that could explain the differences between the 150 second samples. However, the reasonable good agreement between the two integrated hydrogen cyanide samples and the identical ash suggest that, in spite of brief fluctuations, the overall behavior of the two burns was similar.

A-2162

PROJECT A-2162

ANALYSIS AND CHARACTERIZATION OF CARPET WASTES SAMPLES

by

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Report No. 3

for

HAGUE INTERNATIONAL

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January 12, 1979

GEORGIA INSTITUTE OF TECHNOLOGY

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FIGURES

TABLES

1. ABSTRACT

Six burning experiments on a continuous basis were conducted in a modified Riteway stove. The air input rate was monitored and was varied from 3.2 cfm (-70 percent of excess stoichiometric air) to 24 cfm (129 percent of excess stoichoimetric air). The firing rate with the carpet waste was 57,471 Btu/hr for all experiments. The carpet waste sample had a calorimetric heating value of 7,562 Btu/lb and an ash content of 29.9 percent. The stoichoimetric air was calculated to be 10.5 cfm based on the elemental analysis of the carpet waste.

The analytical results on the flue gases showed that with excess stiochiometric air, carbon monoxide, nitrogen oxides, methane and amines were absent. Hydrogen cyanide levels, based on the data, should be in the range of 10 ppm at the point source of the stack exit. It seems reasonable to expect this value could be reduced further with excellent secondary burning. The particulates emissions from these data show that some control of the particulates would be required. In a well designed combustion furnace, it might be expected that the particulates would be lower than obtained in these experiments.

Based on the results of these experiments, it should be feasible to burn carpet wastes as a fuel in a well designed combustion facility.

2. INTRODUCTION

The results from the open-grate burning experiments with carpet waste showed that some continuous burning experiments were needed. The major objective of these experiments was to burn the carpet waste on a continuous basis and to analyze the combustion gases for the major gaseous components and particulate material. In order to accomplish these continuous burns, a Riteway stove was selected. The stove was modified so that the input air could be monitored and the carpet waste could be fed into the stove on an intermittent basis. Six experiments were conducted with this set-up in which the input air varied from minus 70 percent to plus 129 percent of stoichiometric air. Representative gas samples were obtained and analyzed for nitrogen, oxygen, carbon dioxide, carbon monoxide, methane, nitrogen oxides, hydrogen cyanide, and amines. In two experiments, particulate samples were collected.

3. EXPERIMENTAL

3.1. Carpet Waste

The carpet waste for these experiments was composed of 50.4 percent carpet selvage, 14.2 percent of splices and scraps, 6.4 percent carpet lint and 29.0 percent cellulosic waste such as cardboard boxes and paper towels. It was necessary to cut the carpet material into small pieces so that it could be fed into the stove. A sample of the composite feed gave the following analysis:

Elemental	
Carbon	42.25%
Hydrogen	5.8%
Nitrogen	0.55%
Ash	29.9%
Oxygen	21.43% (difference)
Heating Values	
Calculated	8,124 Btu/lb.
Experimental	7,562 Btu/lb.

3.2. Analytical Techniques

The major components in the flue gas samples - nitrogen, oxygen, carbon dioxide, carbon monoxide and methane-were determined by gas chromatographic techniques. The nitrogen oxides were determined with MSA detector tube No. 83099; hydrogen cyanide, MSA detector tube No. 93262; and amines, MSA detector tube No. 92115 which detects ammonia,ethyamine, methyamine and triethylamine. In two of the burning experiments, an aliquot of dry flue gases was passed through a fiber-glass filter for collection of the particulates.

3.3. Modified Riteway Stove

A Riteway stove, Model 37, was obtained for modification for the continuous burning experiments with carpet wastes. Schematic views of the Riteway stove, which is designed for burning wood and coal, and the specifications of Model 37 are shown in Figure 1. These schematics and specifications are taken from the company literature*.

The modified stove is shown in Figure 2. The stove was modified so that the air input could be metered. The entrance for secondary air was sealed. The door was fitted with a fuel feed system as shown in Figure 2. The inside diameter of the fuel feed tube was 4 inches and the distance between the air-tight seals was 9 inches. A rake was installed so that the carpet waste could be leveled as it was added. Three thermocouples were installed as shown. The sample line for flue gas samples was positioned just above the elbow which was attached to the stove exit for flue gases.

3.4. Combustion Experiments

Six combustion tests were conducted in the modified Riteway stove with carpet wastes. The input air was varied from 3.2 cfm to 24 cfm. The carpet waste was introduced on a semi-continuous basis with fuel introduction every 30 seconds. The fuel input rate was 7.6 lb/hr., which is equivalent to a heat rate of 57,471 Btu/hr. based on the experimental calorimetric heating value of 7,562 But/lb. The input carpet fuel was leveled with the bed rake after each addition. Before starting the combustion experiments, carpet waste was burned in the stove so as to build up an ash bed on the

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* Riteway Manufacturing Co., P.O. Box 6, Harrisonburg, VA 22801.

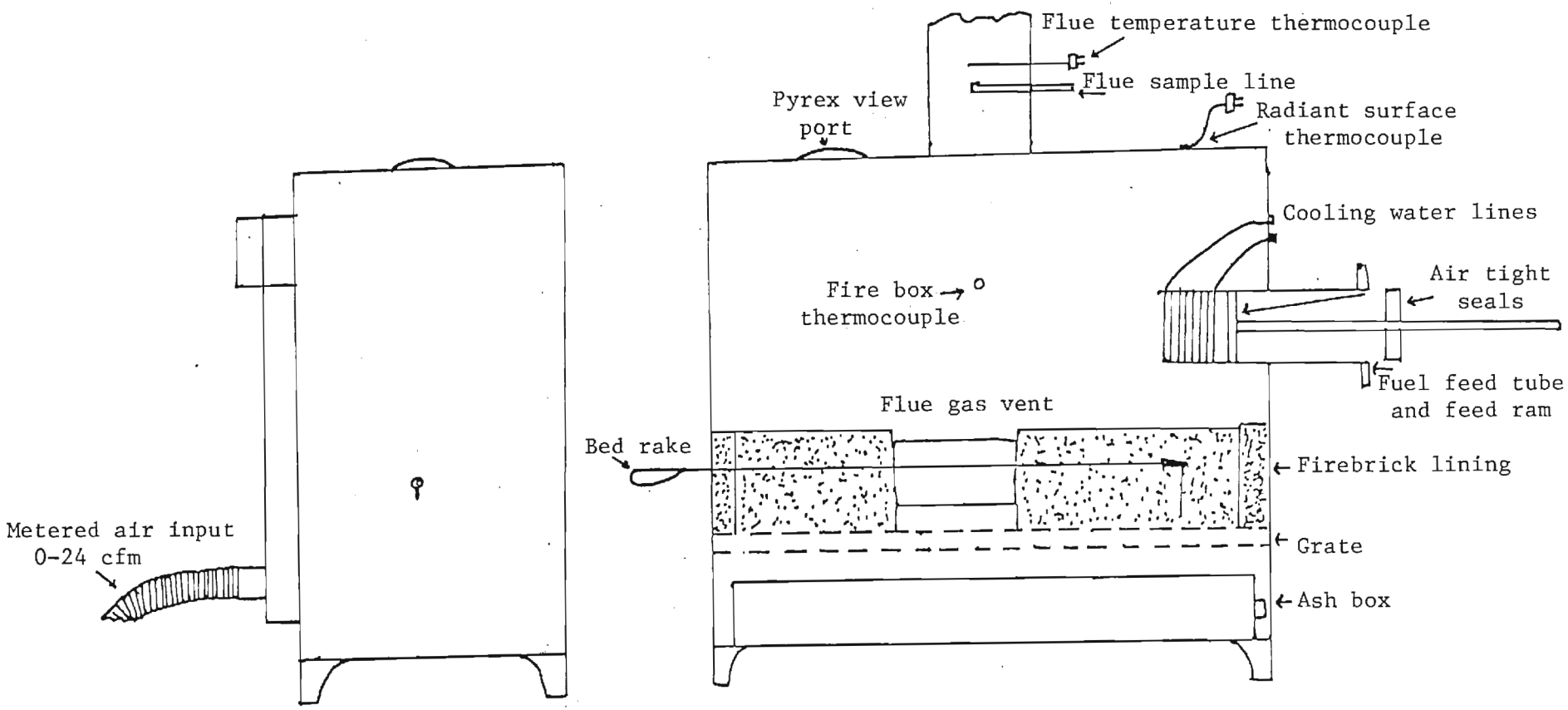

Figure 2. Modification Of Riteway Heater

on the grates to serve as a support for the carpet fuel. The air-input rate was the only variable that was changed in conducting the burn experiments. During a given test burn, the input air was monitored and the temperature as indicated by the thermocouples was recorded continuously. The flue gases were sampled continuously during the run. The stoichiometric air was calculated to be 10.5 cu ft/min. based on the elemental analysis in section 3.1.

4. RESULTS

Table 1 gives the monitored air flow input rates along with the calculated percent of excess stiochiometric air and percent excess air based on the flue gas analysis. It was observed that in runs 1 and 2 that there was

Table 1. Air Flow Rates

Run Number	Input Air: Monitored Rate cfm	Input Air: Percent of Excess Stoichiometric Air	Percent Excess Air Based On Flue Gas Analysis
1	3.2	- 70	126
2	8.4	- 20	163
3	15	43	183
4	15	43	160
5	18.75	79	221
6	24	129	1016

incomplete burning of the carpet waste. The percent excess air values, based on the flue gas analysis,are much greater than the percent excess stoichiometric air. Some additional air was introduced in adding fuel to the stove, but this quantity would not account for the values obtained. It has been reported that when the excess air in flue gases is more than about 200 percent, one must revert to actual measurement of both fuel and air flows*. It is suggested, therefore, that calculations based on these experiments should be made with measured input air rates and the constant fuel rate.

* Energy Management Series, NBS Handbook 124, National Bureau of Standards, Washington, D. C. 20234.

The gas analyses (Tables 2 and 3) did not show the presence of any carbon monoxide, hydrogen, NO_x or amines (organic nitrogen compounds). In runs 1 and 2, some methane was detected, but none in the succeeding runs in which a larger amount of excess air was used. The hydrogen cyanide concentration in the flue gases showed a decrease as the amount of excess air was increased. Run number 4 does not fit the pattern, and there is no apparent reason for this discrepancy. The data indicate very strongly that in the range of 43 percent excess air (based on air input rates) the hydrogen cyanide level would be in the range of 10 parts per million at the point source of the stack exit. With excellent secondary combustion, the hydrogen cyanide could probably be reduced to a lower level than 10 ppm.

The particulate loadings for Runs 4 and 5 were calculated for a 10,000,000 Btu/hour boiler based on the monitored input air rate and the firing rate for the stove of 56,471 Btu/hour. The calculated values from the data for Runs 4 and 5 were 3.48 lb and 3.81 lb. particulates per hour, respectively. Particulate emissions should not present an insurmountable problem for the utilization of carpet wastes as fuel.

The temperature measurements at the three locations of the modified Riteway stove are given in Table 4. These temperatures are relatively low compared with flame temperatures. It should be stated that the Riteway stove is manufactured primarily as a heater and has a relatively large surface area from which heat can be dissipated. Also, the excess air would have a cooling effect on the hot combustion gases.

Table 2. Analytical Data on Flue Gases*

Run Number	Volume Percent				
	N_2	O_2	CO_2	CO	CH_4
1	82.3	12.1	6.93	0	0.025**
2	81.3	13.3	5.77	0	0.01
3	81.4	13.9	5.31	0	0
4	80.0	13.0	6.1	0	0
5	79.8	14.5	4.9	0	0
6	79.9	19.2	0.72	0	0

* These gases were analyzed by gas chromatography. No hydrogen was detected in any of the gas samples.

** In run 1 only, 0.035% of ethylene was detected, and 0.006% of ethane. No other gaseous hydrocarbons were detected in the gas samples.

Table 3. Analytical Data on Flue Gases and Particulates

Run Number	Pollutants (ppm)*			Particulates**
	NO_x	HCN	Amines	
1	0	65	0	-
2	0	30	0	-
3	0	10	0	-
4	0	42	0	10.8 mg
5	0	12	0	12.6 mg
6	0	4.5	0	-

* MSA detector tubes were used: NO_x, No. 83099; HCN, No. 93262; Amines, No. 92115 (detects ammonia, ethylamine, methylamine, and triethylamine). Mine Safety Appliance Co., Pittsburgh, Penna. 15208

** Measured for runs 4 and 5 only. An aliquot of the flue gases was passed through a fiber-glass filter for collection of the particulates. The quantities given are for the total aliquot.

Table 4. Temperature Measurements, °F

Run Number	Location of Thermocouple		
	Gas Over Burning Bed*	Flue Gas in Exit Stack	Radiant Surface of Stove
1	600	550	380
2	730	560	420
3	740	560	460
4	780	640	380
5	730	530	370
6	700	520	400

* Thermocouple located about 14 inches above fire bed.